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Validation of the United States Air Force Bird Avoidance Model

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Abstract Since 1986, bird strikes have caused 33 fatalities and nearly $500 million in damage to United States Air Force (USAF) aircraft. To reduce these losses, the USAF developed a Bird Avoidance Model (BAM) to evaluate low-level training routes for bird-strike hazards throughout the contiguous United States. The current BAM, developed during the 1980s, incorporates waterfowl and raptor species, which account for most (69%) of the damaging bird strikes to military aircraft flying low-level routes. Because changes have occurred to waterfowl and raptor populations throughout North America, there is speculation that the BAM (developed and currently run with historical waterfowl and raptor data) may not accurately predict current bird-strike hazards. Therefore, we compared bird-strike hazards predicted by the BAM for those low-level routes where waterfowl or raptor strikes occurred with a random selection of published low-level routes where waterfowl or raptor strikes were not reported. Mean predicted bird-strike hazards for both waterfowl and raptors were greater ($P \leq 0.02$) for routes where strikes had occurred than for routes where strikes by these species had not occurred. Thus, the BAM predicted mean bird-strike hazards along low-level training routes for the military and, when properly used, can assist with flight planning to minimize strikes with waterfowl and raptors.

Key words aircraft, Air Force, BAM, bird strike, hazard, military, model, raptor, waterfowl

Aircraft collisions with birds (bird strikes) have occurred since the beginning of aviation (Solman 1978, Richardson 1994, Thorpe 1996). Since 1986, bird strikes have caused 33 fatalities as well as nearly $500 million in damage to United States Air Force (USAF) aircraft (Lovell 1997). On average, USAF aircraft incur 2,500 bird strikes/year, most during fall and spring migration (Lovell 1997). About 69% of all USAF bird strikes occur below 305 m elevation above ground level (AGL), and 26% of known USAF bird strikes occur along low-level training routes and ranges (Lovell 1997). Such low-level military flights are especially vulnerable to strikes because these flights typically occur at high speed (e.g., 350-550 nautical miles [nm]/hr) and at low altitudes (e.g., 30-300 m AGL) where birds commonly fly (DeFusco 1993). Low-level incidents represent 65% of the damage caused by bird strikes to USAF aircraft (R. DeFusco, Col., USAF Academy, Colorado Springs, Colo., personal communication). Waterfowl (ducks and geese) comprised 13.4% and raptors (hawks and vultures) 56.2% of the damaging strikes (C. Burney, Lt., USAF, Albuquerque, N.M., personal communication).

In the early 1980s, the USAF Bird Aircraft Strike Hazard (BASH) Team developed a computerized Bird Avoidance Model (BAM). The BAM is a DOS-based program written in FORTRAN that computes bird-strike hazards for areas within the continental United States (Skinn et al. 1981). The purpose of the

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BAM is to reduce bird strikes to aircraft on low-level training missions by providing information to pilots on locations and times of elevated bird activity based on historical data (e.g., refuge and field surveys, migration data and routes). The BAM has been used extensively by aircrews, flight schedulers, and low-level route planners since its implementation in 1983 (Lovell 1997). The BAM was designed to reduce bird strikes in low-level training environments where bird management is impractical. It was never intended as a management tool to reduce bird strikes in the airfield environment where airport-based management programs are more appropriate (Dolbeer et al. 1993). About 96% of bird strikes to civil aircraft occur in the airfield environment (e.g., approach, landing, and takeoff) (Cleary et al. 1997).

Populations of many bird species commonly involved in bird strikes have increased in the last 20 years (Lovell 1997). Restrictions in using pesticides and other chemicals that historically affected bird reproduction, enhanced bird management and protection programs, and adaptation by some of these species to human environments contributed to population increases (Hatch 1995, Rusch et al. 1995, Dwyer et al. 1996). Models using historic data may not accurately predict current probabilities of striking bird species hazardous to military aircraft.

In 1982, Short (1982) evaluated the ability of the BAM to predict bird-strike hazards along low-level training routes. The evaluation did not include raptor species, and data on waterfowl bird strikes was limited. The BAM has not been evaluated since 1983. Consequently, our objective was to evaluate the BAM by comparing the predicted bird-hazard rating for low-level training routes where strikes involving waterfowl and raptors have occurred with a comparable set of randomly selected routes where bird strikes have not occurred. We assumed bird strikes were random regarding aircraft type and number of flight hours/low-level route. This method of evaluation should be valid because strike data for individual routes were not used to develop the BAM and are therefore independent of the model.

Table 1. Bird-strike hazard categories and bird-hazard ratings for waterfowl and raptors from data output from the United States Air Force Bird Avoidance Model.

Species Group	Hazard categories	Bird-hazard rating[a]
Waterfowl	Note	30–99
	Caution	100–999
	Warning	>999
Raptors	Note	3–9
	Caution	10–19
	Warning	>19

[a] Number of expected bird strikes/1 million nautical miles of flight.

Methods

Bird-strike hazard levels for waterfowl and raptors in the BAM are organized into note, caution, and warning categories (Table 1), based on the bird-hazard rating (the predicted number of bird strikes/1 million nm of flight) of a particular military route or area. Bird-strike hazard levels used in the BAM are more conservative for raptors than for waterfowl because the soaring habits of raptors increase the probability of collisions with aircraft.

The BASH Team compiled all reported bird strikes to USAF aircraft since 1985 into a bird-strike

Figure 1. Waterfowl and raptors cause the greatest number of damaging strikes to aircraft in the United States.

Table 2. Bird-hazard rating[a] predicted by the United States Air Force Bird Avoidance Model for low-level routes where strikes involving waterfowl or raptors have occurred (1985–1996) and for an equal number of randomly selected low-level routes where strikes have not occurred.

Species	n	Routes where strikes have occurred			Routes where strikes have not occurred		
		$\bar{x}$	S. D.	Range	$\bar{x}$	S. D.	Range
Waterfowl	86	24.1[b]	61.1	0–505.4	12.7[b]	40.5	0–248.1
Raptors	259	4.8[c]	1.7	0–14.8	4.4[c]	1.6	0–7.4

[a] Number of expected strikes/1 million nautical miles of flight.
[b] Means are different (F=22.29; 1, 170 df; P<0.01).
[c] Means are different (F=5.74; 1, 516 df; P=0.02).

database. We searched the database for strikes involving waterfowl or raptors that occurred on defined low-level routes from 1985 to 1996. We calculated the bird-strike hazard rating for each of these low-level routes for the month and time of day when each strike occurred. We then randomly selected an equal number of low-level routes where there were no strikes by waterfowl or raptors. We calculated bird-strike hazard ratings for each of these routes using a random month and time of day. For each species group, we used a 1-way ANOVA (SAS Institute, Inc. 1990) to test the null hypothesis of no difference in mean bird-hazard rating among routes with and without bird strikes. Because the variance associated with the mean bird-strike hazard was large for waterfowl, we performed a log-transformation to normalize waterfowl data (Steel and Torrie 1960).

Additionally, we assigned each hazard rating for waterfowl and raptors as either "no hazard" or "hazard." A rating of "no hazard" was assigned for hazard levels less than the criteria defined for the "note" category, and a rating of "hazard" was assigned for hazard levels $\geq$ "note" category (Table 1). We used chi-square analysis to test whether the frequency distribution was similar for "no hazard" and "hazard" ratings between routes with strikes and routes without strikes by raptors or waterfowl.

Results

We identified 86 known low-level routes as having a USAF aircraft strike with waterfowl, and we identified 259 as strikes with raptors. We compared the hazard rating for these routes with 86 and 259 random low-level routes where strikes to waterfowl and raptors were not reported, respectively. The mean bird-hazard rating was significantly greater for routes where strikes had occurred compared to routes where strikes had not occurred for waterfowl (P<0.01) and raptors (P=0.02) (Table 2).

Frequency distributions for "no hazard" and "hazard" levels were different for low-level routes with waterfowl (P=0.07) and raptor (P<0.01) strikes compared to random low-level routes without waterfowl and raptor strikes (Table 3).

Discussion

At the time the BAM was developed, Short (1982) examined the percentage of cases where the model predicted elevated hazards for low-level routes where bird strikes had occurred. Short's evaluation of the BAM, although somewhat subjective and limited by small sample sizes, indicated the potential of the BAM to predict elevated strike hazards. Leshem (1994) showed that by monitoring migratory

Table 3. Frequency distributions of bird-hazard levels predicted by the United States Air Force Bird Avoidance Model for low-level routes where strikes by waterfowl or raptors have occurred (1985–1996) and for an equal number of randomly selected low-level routes where strikes have not occurred.

Predicted hazard level	No. of routes (waterfowl)[a]		No. of routes (raptors)[b]	
	with strikes	without strikes	with strikes	without strikes
No Hazard	71	79	21	42
Hazard[c]	15	7	238	217

[a] Frequency distributions are marginally different (X^2=3.34, 1 df, P=0.07).
[b] Frequency distributions are different (X^2=7.97, 1 df, P<0.01).
[c] Either a note, caution, or warning (Table 1).

Figure 2. Damage to United States Air Force aircraft from bird strikes has exceeded $500 million since 1986.

patterns of birds in Israel and scheduling flight training periods around migration, bird strikes to military aircraft can be reduced.

Our analyses indicated that the current BAM continues to predict greater mean hazard ratings for routes where strikes have occurred compared to routes where strikes have not occurred. Because the strike data are independent of the model, these analyses indicated that the BAM does, on average, provide some prediction of relative strike risk for waterfowl and raptors along low-level training routes. Our findings should reassure users of the current BAM's ability to help reduce waterfowl and raptor strikes along low-level routes.

The current BAM uses historic population data for waterfowl and raptors only and cannot be updated or modified to test for other species. Additionally, this model is complex to use, difficult to interpret, and runs on outdated software. A Geographic Information System (GIS)-based model that incorporates current and more complete population data on an expanded list of bird species deemed hazardous to military aircraft (DeFusco 1996) is in the final stages of development (D. P. Arrington, Maj., USAF, Albuquerque, N.M., personal communication). This GIS-BAM is Windows-driven and may be more applicable to civil aviation (e.g., locating new airports and approach and departure routes) because of its broader applications and abilities. Given the modest success of the current BAM to predict bird hazards, the new GIS-based BAM incorporating current computer technologies and an expanded database should provide significantly improved benefits to military and perhaps civil aviation communities.

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